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SAFE ELECTRICAL PRACTICES IN TWO ARIZONA OPEN-PIT MINES

BY

J. HYVARINEN AND A. D. LOOK

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SAFE ELECTRICAL PRACTICES IN TWO ARIZONA OPEN-PIT MINES[1]

By J. Hyvarinen[2] and A. D. Look[3]

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1/ Work on manuscript completed July 1, 1948. The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7494."

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INTRODUCTION AND SUMMARY

Electricity is used extensively in open-pit metal mines to provide illumination, heat, and power to operate hauling and loading equipment, drills, pumps, signal systems, and other machinery. Good installation and maintenance of equipment and power circuits are essential to minimize the hazards of shock, burns, and fire.

In the 13 years from 1931 to 1943, 20 fatal and 82 nonfatal injuries resulted from the use of electricity in open-pit mines in the United States;[4] these figures represent about 10 percent of all fatalities and 1 percent of the nonfatal injuries. The ratio of fatal to nonfatal injuries from

4/ Bureau of Mines, Electrical and Mechanical Hazards in Metal Mines: Metal-Mine Accident-Prevention Course - Section 6: Miners' Circular 56, table 2, p. 4.

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electricity in such mines was very high during this period; the figures show one fatality to every five accidents from this cause.

Electricity may cause personal injury through abnormalities in equipment, such as short-circuit, accidental ground, overload, and poor contact; however, each year some fatal electrical accidents are due to persons touching uninsulated "live wires." These contact injuries are the result of careless body movements of persons in the vicinity of wires at places not normally frequented, or of accidental contact with live circuits when handling metal objects. Electrical hazards can be minimized by the enclosure or elevation of current-carrying parts; ample working space around equipment, adequate insulation, locking switches in the open or closed position under certain conditions, identifying and warning devices, protective grounding, insulating flooring, platforms, or rubbes gloves, and proper inspection and maintenance.

The purpose of this report is to present some of the safe electrical practices used in two open-pit mines operated by two large copper-mining companies in Arizona. It is hoped that other open-pit operators will benefit by the described practices, which are the result of considerable expenditure and effort on the part of the two mining companies. Electrical hazards in the two mines (designated as A and B) have been reduced greatly, and the companies are to be commended for the institution of safe electrical practices.

ACKNOWLEDGMENTS

The cooperation of the officials of the two companies in permitting publication of this report on their operations and methods is greatly appreciated.

The writers also acknowledge with thanks the helpful suggestions of E. H. Denny, supervising engineer, Bureau of Mines, Salt Lake City, Utah, in the preparation and review of this paper.

MINE A

General Information

Power for the operation of electrical equipment in the open-pit mine is obtained from a modern, company-owned, medium-pressure, high-temperature power plant. The waste gases from smelter operations are utilized for the generation of electricity.

High-Voltage Transmission Lines

Power is transmitted at 13,900 volts alternating current to three transformer stations, each near a load center in the pit, where it is reduced to 2,300 volts for distribution to the working areas and to two converter substations, where it is converted to 860 volts direct current for electric-haulage purposes.

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The transmission lines consist of (1) a flexible structural-steel tower line and (2) a wooden-pole line, both originating at a distribution center near the power plant. The two lines are parallel across rough land for a distance of about 2-1/2 miles and terminate at the pit-transformer stations. The load connected to each circuit is proportioned to its carrying capacity, and each is protected at its origin against overload by oil circuit breakers equipped with overload protective devices. Station-type lightning arresters are installed in each circuit at the sending end and at each transformer station and substation at the receiving end.

Each power circuit consists of No. 00 copper conductors and No. 00 galvanized, stranded, steel-cable static lines installed above the power conductors. Static lines above the high-voltage lines are not used for any special grounding circuits.

Medium-light loading specifications have been used in the design of the lines. All guy wires are equipped with insulators. A colored band is painted around and near the base of each pole to indicate the voltage carried on the various permanent pole lines; the colors for the different voltages are as follows:

Red	13,900-volt circuits
Yellow	2,300-volt circuits
White	Secondary 220- and 440-volt circuits

Transformer Stations

Each transformer station contains three 550-kv.-a., closed-delta-connected transformers, switching equipment, lightning arresters, ground-protection equipment, grounding electrodes, and a spare transformer. The transformers are mounted on steel cars, which are equipped with flanged wheels to facilitate their movement on rails in or out of the stations. The stations are steel-frame structures on concrete foundations.

Figure 1 is a view of a transformer station. The photograph was obtained before the station was enclosed by a fence and shows the type of construction used, the method of mounting the transformers to facilitate movement, lightning arresters, disconnecting switches on the 13,900-volt circuits, the oil circuit breaker, and the ground-protection equipment on the 2,300-volt circuit.

Figure 2 is a close-up view of the ground-protection equipment in the same station, showing the "zig-zag" transformer, resistor, relay, and current transformer (inside of cabinet shown with open door). The photograph was obtained after installation of the fence, which is 6 feet high and of woven wire topped with three strings of barbed wire set outward and upward at a 45-degree angle.

The stations are spaced equidistant around the perimeter of the oval-shaped pit and are on benches or fills on the upper levels of the ore body

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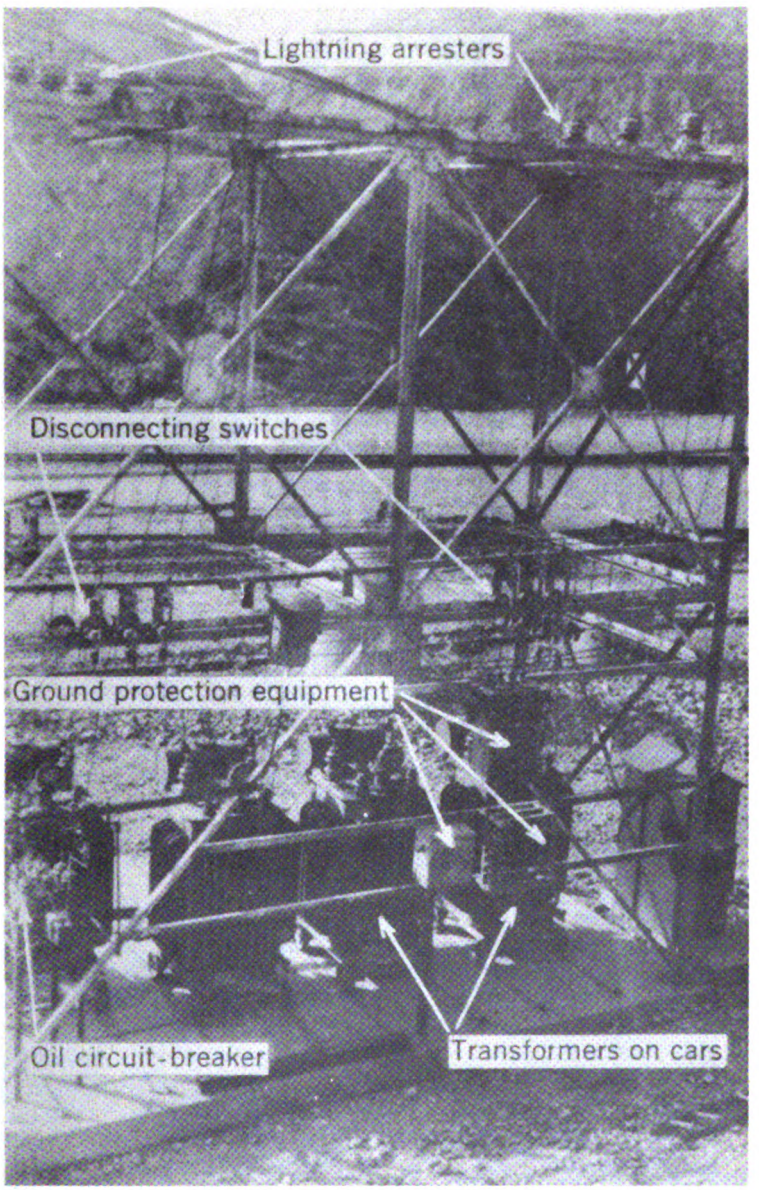

Figure 1. - 13,900 volts to 2,300 volt transformer station. (Prior to installation of fence).

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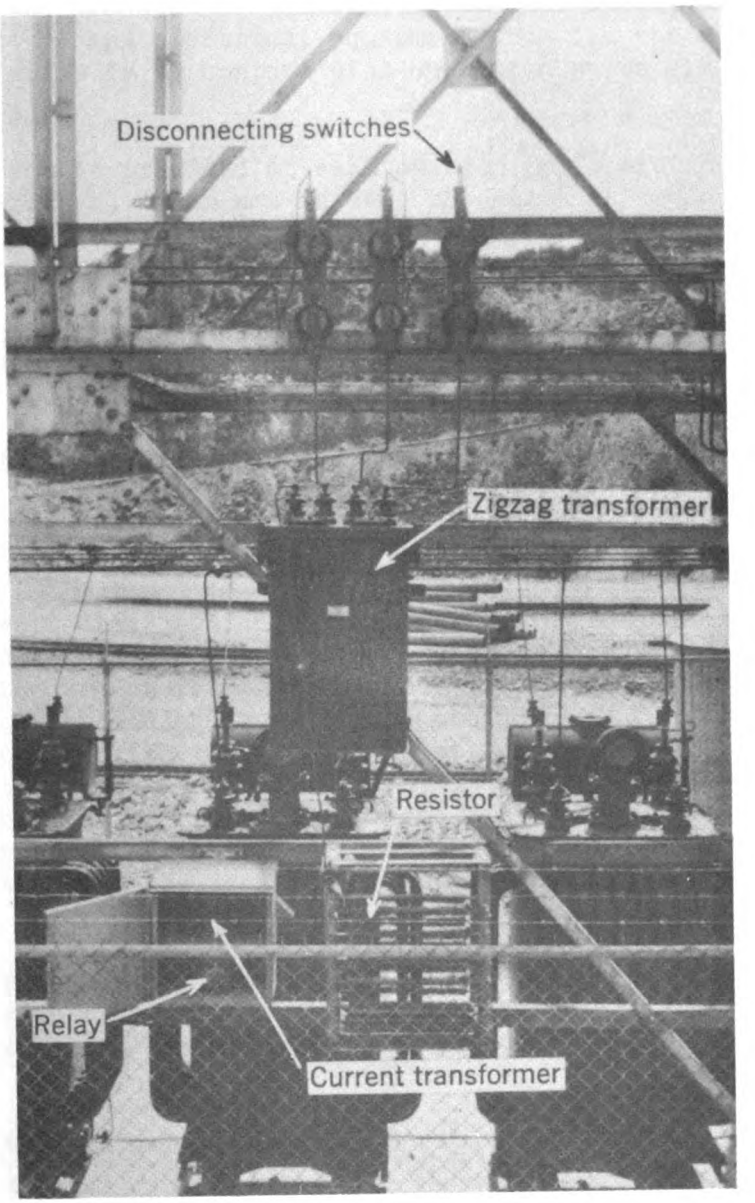

Figure 2. - Close-up view of ground-protection equipment in same station shown in figure 1. (After installation of fence).

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in each area. The stations are constructed where the flammable, oil-filled transformers do not present a fire hazard.

Casings of the transformers, the metallic enclosures, and all metallic frames and covers of any electrical equipment that can become "alive" through failure of insulation or by contact with energized parts are grounded effectively.

A switch stick is provided at each station for operating the high-voltage disconnecting switches. When not in use, the stick is protected from elements of the weather by a water-tight sheet-metal container mounted in a convenient place on the steel frame of the station.

Each station has been designed with ample power capacity at secondary voltage to operate five 5-cubic yard, 2,300-volt, electric shovels and a few churn drills at the same time.

Ample working space (fig. 1) has been provided around the equipment in the stations.

Ground-Protection Equipment

The 2,300-volt distribution system originating at each transformer station is provided with ground protection installed in the station. As the secondaries of the transformers are closed, delta-connected, interconnected star or "zig-zag," grounding transformers are connected to the 2,300-volt, 3-phase lines to establish the neutral point for grounding. To limit the ground-fault current, a grounding resistor is connected between the transformer neutral and the grounding electrode. A low-energy relay is connected to the secondary of a current transformer in the lead between the "zig-zag" transformer neutral and the resistor in the transformer-station ground circuit.

Figure 2 is a close-up view of the ground-protection equipment installed at a transformer station. The following tabulation lists the types and sizes of the individual units in the protection system:

Unit	Size
"Zig-zag" transformer	17.5 k.-va. 2,400 volts
Resistor	108 ohms 2,300 volts, 12.5 amperes
Relay	0.5 to 2.5 amperes
Current transformer	20-ampere primary, 5-ampere secondary

The ground-protection equipment limits the ground-fault current in each distribution system to about 12.5 amperes and trips the oil circuit breaker on the 2,300-volt circuit at ground-fault currents of about 2.5 amperes or more.

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Grounding Electrodes at Transformer Stations

Effective grounding is provided at each transformer station by the use of artificial grounds consisting of 9-inch churn-drill holes about 250 to 300 feet deep. Two grounds are provided, one at each end of the station, and are interconnected to the equipment in the station. A 1,000,000 circular mil copper conductor is imbedded in a charcoal and rocksalt fill in each hole to provide the grounding electrode for the station equipment and the neutral of the ground-protection transformer. A short length of casing is left in the top portion of each hole to keep the earth from "squeezing in." A small stream of water runs into each hole continuously through a 40-foot length of 1-inch pipe imbedded in the top portion of the hole.

Figure 8 is a view of the type of grounding electrode installed at the substations (rectifiers). Similar electrodes are installed at the transformer stations but are without the concrete-top enclosure.

Ground-resistance measurements were obtained with a Vibro-ground tester on the transformer-station grounding circuits, as follows:

Transformer station	Grounding connection	Ohms, resistance
No. 1	Grounding electrodes	1.5
	Water line	3.5
No. 2	Grounding electrodes	1.0
No. 3	Grounding electrodes	2.4

The results of the tests show that very low-resistance grounding connections are available at the mine by use of these multiple-electrode artificial grounds.

Secondary Distribution Circuits

The power is distributed at 2,300 volts on wooden-pole lines originating at the transformer stations. Each line angles, in a counterclockwise direction, down the edge of the pit from bench to bench and skirts the edge of the active workings. Branch lines originate from distribution centers on these main lines.

Medium-light loading specifications have been followed in the design of the lower-voltage lines. Static lines of galvanized stranded steel wire are installed over the power circuits; these lines also are used as grounding conductors to the neutral of the ground-protection transformers. Insulated guy wires are in general use.

Pole-mounted disconnecting switches and oil circuit breakers are installed between the main lines and branch lines for sectionalizing purposes.

In figures 3 and 4 are shown poles that have bands of yellow paint identifying them as carrying 2,300-volt circuits.

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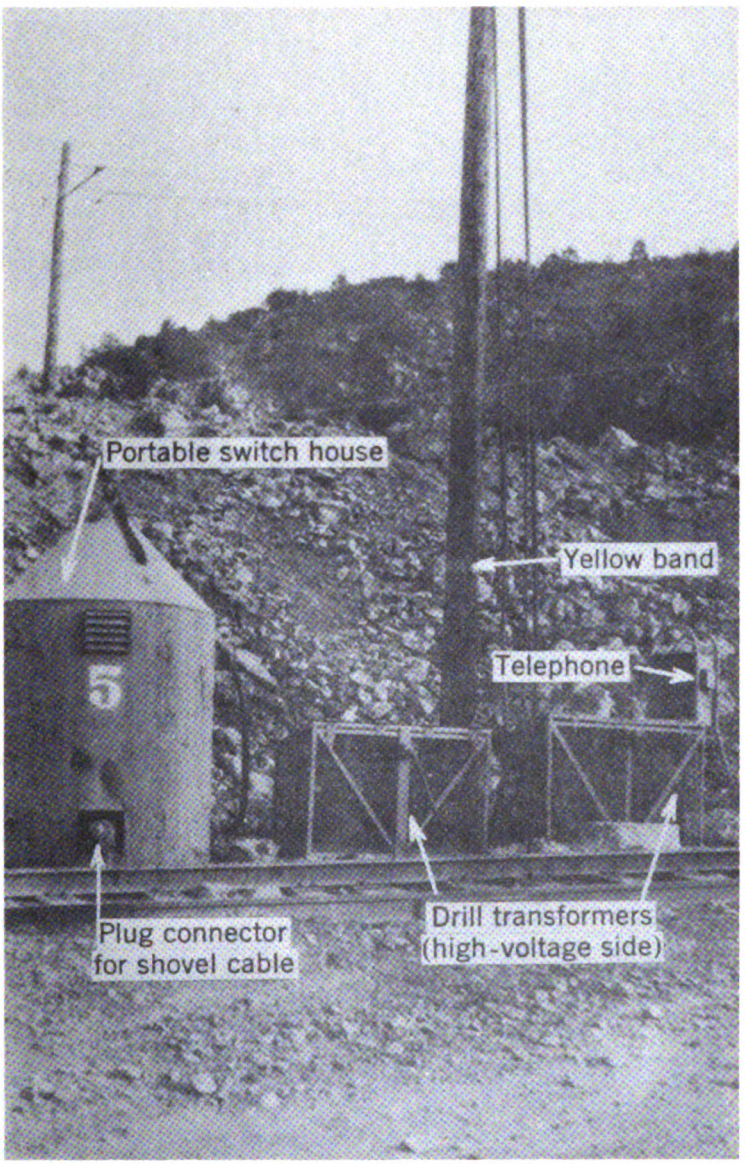

Figure 3. - Portable switch house; portable transformer stations for drills (high-voltage side); pit telephone installation.

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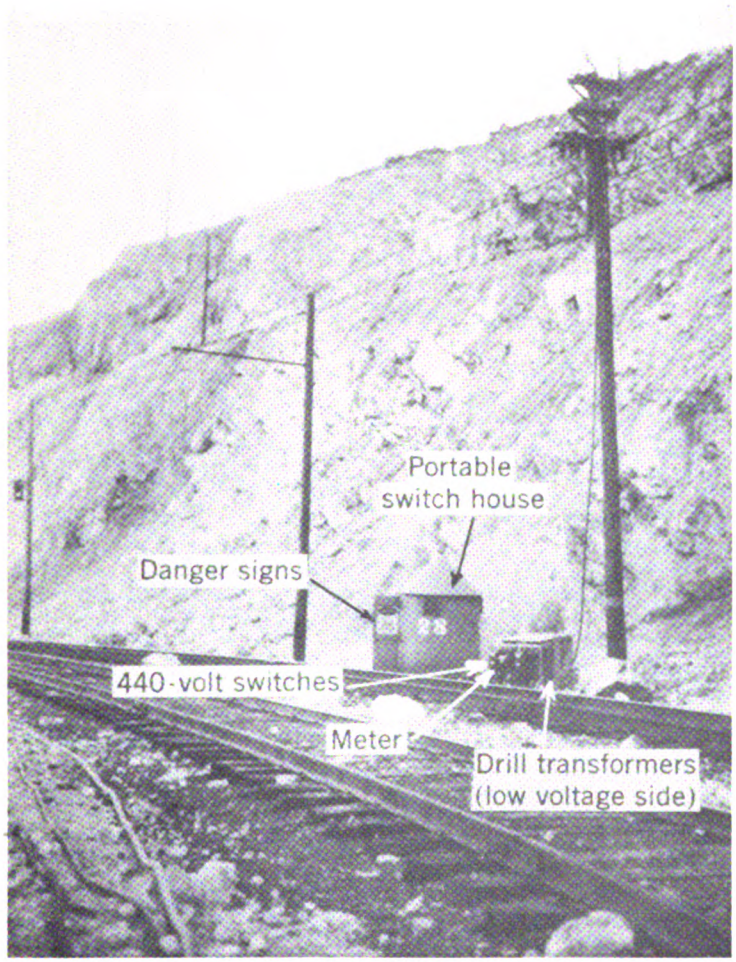

Figure 4. - Portable switch house; portable transformer station for drills (low-voltage side).

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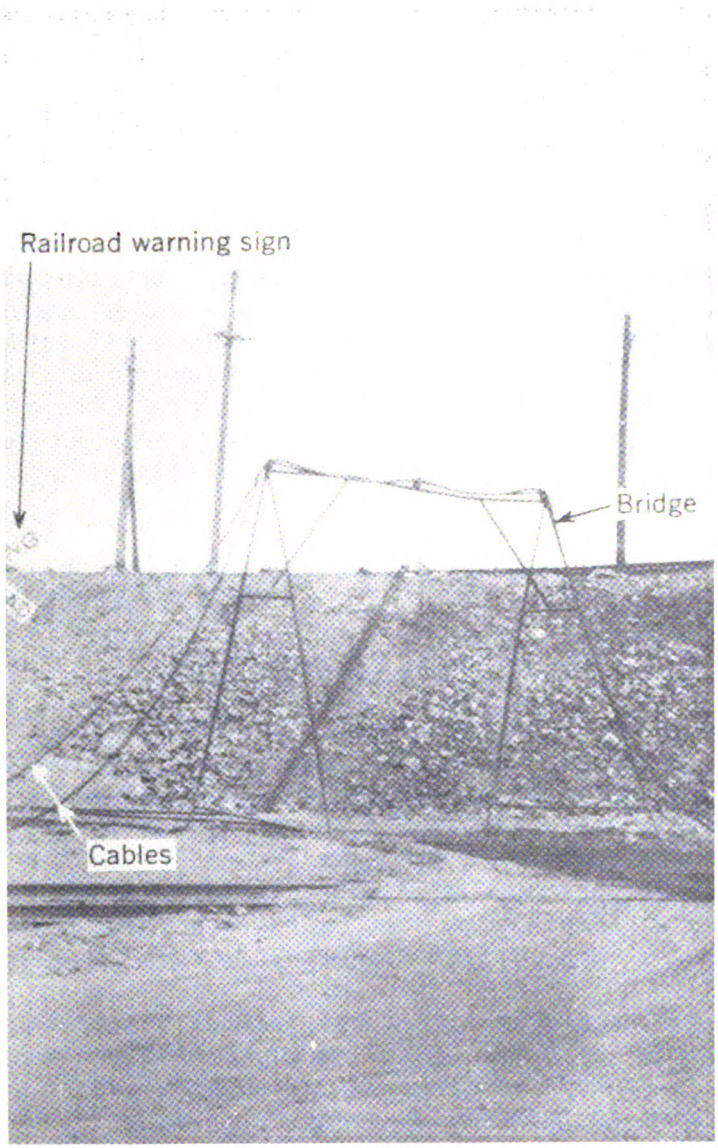

Figure 5. - Bridge for cables.

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Portable Switch Houses

Protective devices for the electrical equipment and cable of each shovel are installed in portable switch houses at the line end of each cable, as shown in figures 3 and 4. Each switch house contains cut-outs, a switchboard with metering equipment, an oil circuit breaker of the panel-mounted type, equipped with overload and ground tripping devices, and a plug-type connector for the shovel trailing cable. The cylindrical-type houses are made of heavy sheet metal, which will stand a considerable amount of abuse. They are moved by means of track-mounted cranes and, consequently, need not be provided with skids.

The ground tripping equipment consists of an instantaneous tripping relay that is connected to a current transformer installed in the grounding conductor; it will trip the oil circuit breaker when energized at a predetermined current. The ground circuit between the shovel and the neutral of the ground-protection transformer in the transformer station consists of the ground wires in the trailing cable, the current transformer in the switch house, the ground wires in the cable from the switch house to the static line on the overhead pole line, and the static line proper; all are connected in series to form a continuous electric circuit. The ground trip in each switch house is adjusted to operate at a slightly lower current rating than the trip at the transformer station.

"Danger" signs are painted conspicuously on the doors to the switch houses, as shown in figure 4.

Shovel Trailing Cables

The conductors of the trailing cables are insulated for 5,000 volts. Cables are handled with tongs and, when long moves are made, power is disconnected and the cables are moved by hand. According to company rules, energized trailing cables should not be touched by hands, feet, or other parts of the body, and should not be run over by automobiles or trucks. Figure 5 shows a bridge for cables of the type used at roadway crossings in the pit. Cables are placed on a bridge with 2-1/2-inch diameter wooden poles equipped with strap-iron forks at the upper ends.

New trailing cables for shovels are sectionalized in 800-foot lengths; if necessary, as many as three or four lengths are used in a cable, connections being made by means of plug-type connectors, such as shown at the base of the switch house in figure 3. Cables are replaced as soon as a defect is observed, and temporary splices are not tolerated. A damaged cable is replaced, removed to the shop, and repaired; all splices are vulcanized. Excess trailing cable to each shovel is kept coiled in a large figure-eight loop some distance back of the shovel and protected from falling rocks and blasting operations.

Shovel frames are kept as close to a ground potential as possible by the grounding circuit of the ground wires in the cables and the static lines, which are connected to the very low-resistance grounding electrodes at the

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transformer stations. The ground-protection equipment limits the ground-fault current and disconnects the power source before dangerous voltages appear between the shovel frame and ground.

Drill Transformers and Trailing Cables for Drills

Figures 3 and 4 show front and rear views, respectively, of the portable transformer stations that supply power for operating the drills. The screened enclosures contain three 10-kv.-a., 2,300- to 440-volt, oil-filled transformers. Hinged, steel-plated, slanted tops on the enclosures facilitate inspection and repair. Cut-outs switches are installed inside the enclosures on the primary circuits, and the secondary circuits are connected to safety switches as shown in figure 4. A wattmeter also is installed on the secondary circuit to record the power consumed by one or more drills. Three-phase lightning arresters are installed to protect the wattmeter.

Drill cables are sectionalized at 500-foot lengths, and, if necessary, more than one length is used to a drill. Miller-plug connectors are used to make all connections. Damaged cables are removed from service promptly and repaired, spliced, and vulcanized. Excess trailing cable to each drill is kept coiled on a bracket mounted on the side of the housing enclosing the motor and motor controls.

Substations (Rectifiers)

The 13,900-volt alternating current is transmitted to two substations, each installed near load centers, where it is rectified to 860-volt direct current for haulage purposes. Figures 6 and 7 are outdoor views of the two stations showing the concrete foundations, steel-frame structures, brick buildings, 6-foot woven and barbed-wire enclosures, static lines above each station, and the cabinets containing controls for the high-voltage circuits to the transformers.

Lightning arresters and a triple-pole, single-throw, outdoor disconnecting switch are installed in each incoming 13,900-volt line. Operating handles on the switches are grounded effectively and are kept locked at all times whether in the connected or disconnected positions. Fuses also are installed in the high-voltage lines between the switches and the oil circuit breakers ahead of the transformers. The oil circuit breakers are installed in sheet-metal, enclosed cabinets and are equipped with automatic tripping devices of the type that attempt to close the circuit three times in case of a short circuit before "locking out."

The secondary windings of each transformer consist of two 6-phase circuits, each of which has its own insulated circuit and switches to facilitate disconnecting a rectifier for repairs without interfering with the operation of other rectifiers. Distilled water is circulated in the cooling system of each rectifier by a pump; the water, in turn, is air-cooled by a fan.

Static lines of No. 00 galvanized, stranded steel wire are installed in a network above each station; each network is grounded effectively.

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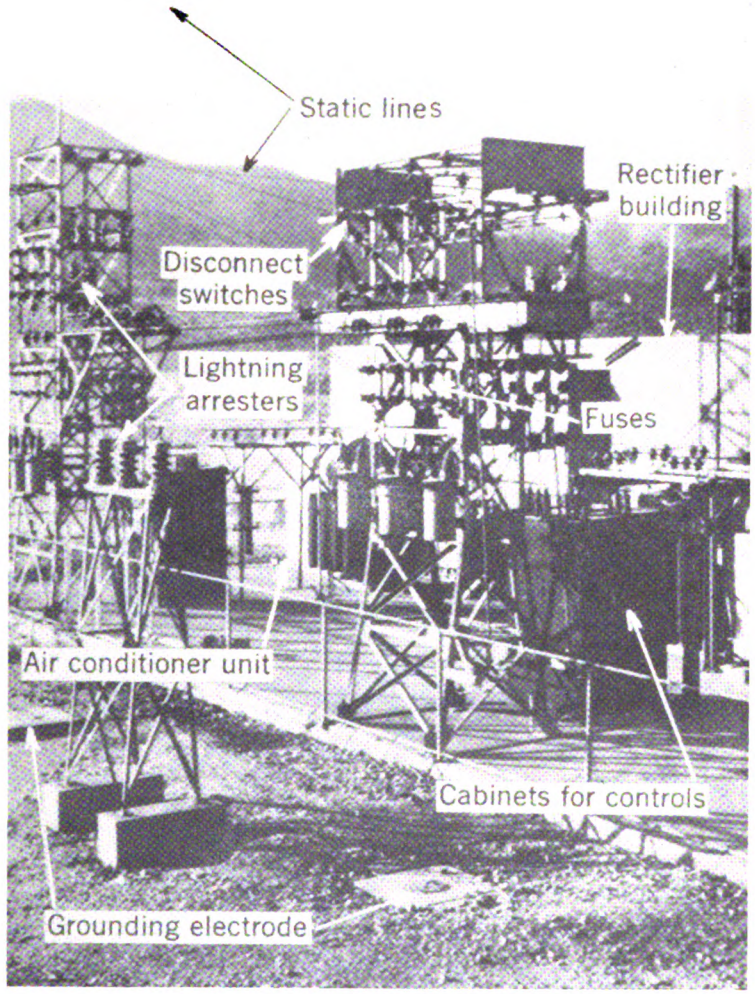

Figure 6. - 13,900 volts A. C. to 860 volts D. C. Substation. Note: Tops of enclosures for grounding electrodes in foreground.

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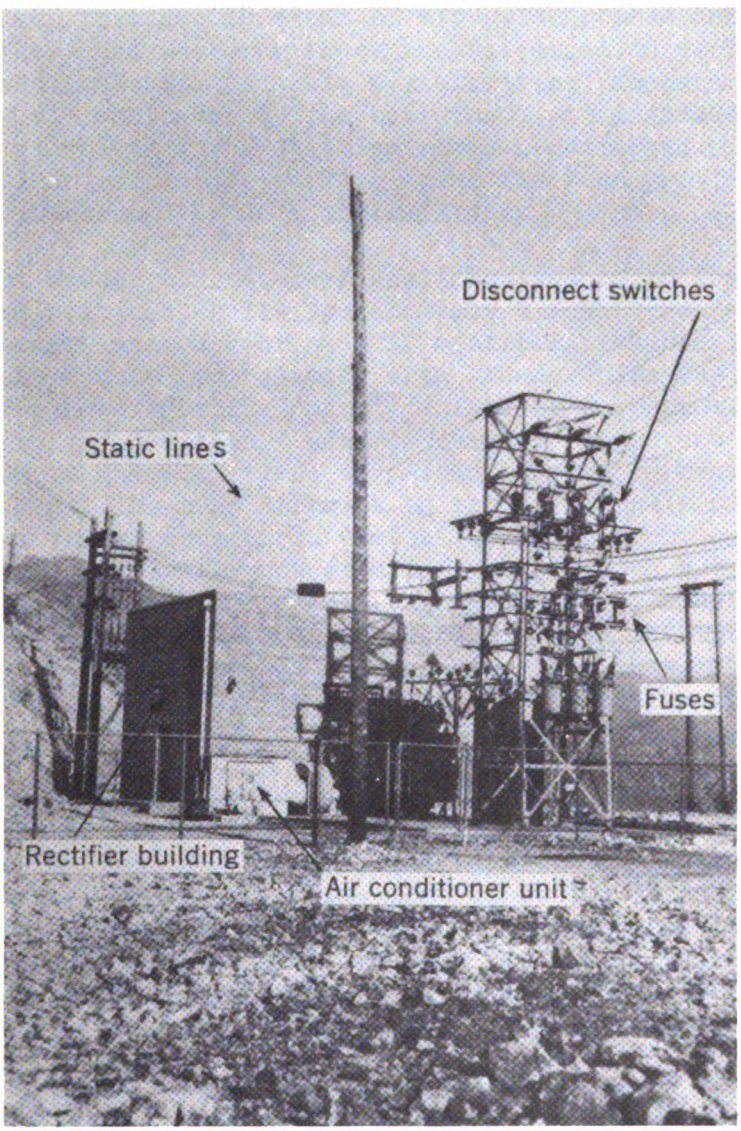

Figure 7. - Substation. Note: Static lines and air-conditioner unit.

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The mercury-arc rectifiers, switchboards, and protective devices for the direct-current circuits are housed in air-conditioned brick buildings shown in figures 6 and 7. The stations are automatic in operation, and no attendants are present except for an inspection each morning of temperatures, vacuum readings, load, etc., and also for necessary servicing. Entrances to the stations are kept locked at all times unless an authorized person is present. Rubber mats have been provided in front of all switchboards and around all mercury-arc rectifiers and wherever shock hazards exist on equipment in the buildings. Fire extinguishers suitable for electrical fires are located strategically near the entrances to the buildings, and maintenance supplies and equipment are stored in fire-resistive rooms constructed of masonry and provided with metal doors. Ample working space has been provided around the equipment on both indoor and outdoor installations.

Direct-current feeder circuits are sectionalized as to load centers on the haulage systems. Automatically operated air circuit breakers are installed in each feeder, and each breaker is equipped with overload protective devices. The breakers also are equipped with "feeder circuits," which prevent the reclosing of the breakers if a "short" exists or a locomotive controller has been left in an "on" position. Reverse-current relays are installed between the transformers and rectifiers to prevent direct current from backing into the transformers. The trip circuits on the air circuit breakers and on the reverse-current relays operate on 48-volt direct current supplied by storage batteries that are well-protected in sturdy screen enclosures in each building. Tripping devices also protect the equipment by opening the circuit to a rectifier whenever the vacuum decreases in a rectifier tube, excitation discontinues, or the temperature becomes too high in a tube. The circuits of each rectifier are metered for loads and voltages by instruments mounted on the switchboard.

The 860-volt direct-current feeders consist of 1,000,000 circular-mil wires, each of which is protected for high-voltage surges by lightning gaps installed near the substation. The disconnecting switch on each feeder circuit is equipped with a sensitive remote-control button that will open the air circuit breaker first if an attempt is made to open the Switch under load, thus preventing an arc at the switch. Feeders are installed between the two substations and, in event of breakdown of equipment in either station, provide a means of maintaining power supply on the direct-current circuits.

Heavy copper grounding buses are installed in concrete channels under the rectifiers in each station. One end of a bus is connected to the track rails and the other end is connected to the grounding electrodes. Copper plate 1/32-inch thick and 2 feet wide is buried in the soil just outside the station enclosures to provide a grounding bus around the station to which the fences and some of the outdoor equipment are grounded. The steel fences are grounded to these plates by No. 0000 wire, and the plates are connected to the grounding electrodes.

The grounding electrodes consist of 1,000,000 circular-mil copper conductors, and a quantity of scrap copper wire imbedded in charcoal and rocksalt fills in 9-inch diameters by 275-foot deep churn-drill holes. The fill in each

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hole is kept moist by a continuous stream of water through a 40-foot length of 1-inch pipe imbedded in the fill at the top of each hole. Short lengths of casing are left in the top portions of each hole to prevent caving of the sides of the holes. The top of each churn-drill hole is enclosed in concrete, and each enclosure is provided with a cover plate that can be removed to make connections to the electrodes and to adjust the valve regulating the water stream, as shown in figure 8. Water is piped around the pit for drilling purposes and taps are inserted at convenient places for supplying water for the grounding electrodes. In the foreground of figure 6, the tops of two of six churn-drill holes are shown at a substation. The six electrodes are tied together and are connected to a grounding electrode consisting of two 1,000,000 circular-mil copper ground leads, which are connected to a copper plate and some scrap copper imbedded in cinders at the bottom of a near-by 500-foot shaft. The bottom of the shaft is damp at all times.

The resistance measurements of the substation grounding networks, obtained with a Vibroground tester, were as follows:

Location	Ohms, resistance
Substation shown in figure 6	1-3/4
Substation shown in figure 7	2-1/4

The tests showed that very low-resistance grounding networks are available at the substations.

Direct-Current Trolley and Feeder Wires

Diesel-electric and combination storage battery-trolley locomotive are used for haulage purposes in the mine. The haulage system has 43 miles of track, of which about 50 percent is electrified for a trolley system. The trolley wires are suspended from wooden poles by insulators attached to brackets on single tracks or by insulated cross catenaries on double-track haulage. Figure 9 is a view of a section of the electrified haulageway between the mine and the reduction works showing the cross catenaries, the messenger (copper-wire feeder), intermediate, and contact wires above each track, and the trolley-wire feeders and block-signal system wires (shown on the pole at the right edge of the photograph). Guy wires equipped with insulators are used throughout the system. The rail circuit is well-bonded by No. 0000 welded bonds.

Signal Systems

An automatic block-signal system has been installed on the main haulageways between the pit and the reduction works. It controls the movement of ore trains from the approaches of the pit to the reduction works and also trains of empties part way back to the pit on the return track.

The 440-volt, 60-cycle, alternating-current signal systems obtain their power from either of two sources - (1) the power source at the pit or (2) the power source at the plant. Relay-operated, magnetic, reversing switches are installed to tie in automatically with either source of power when the other

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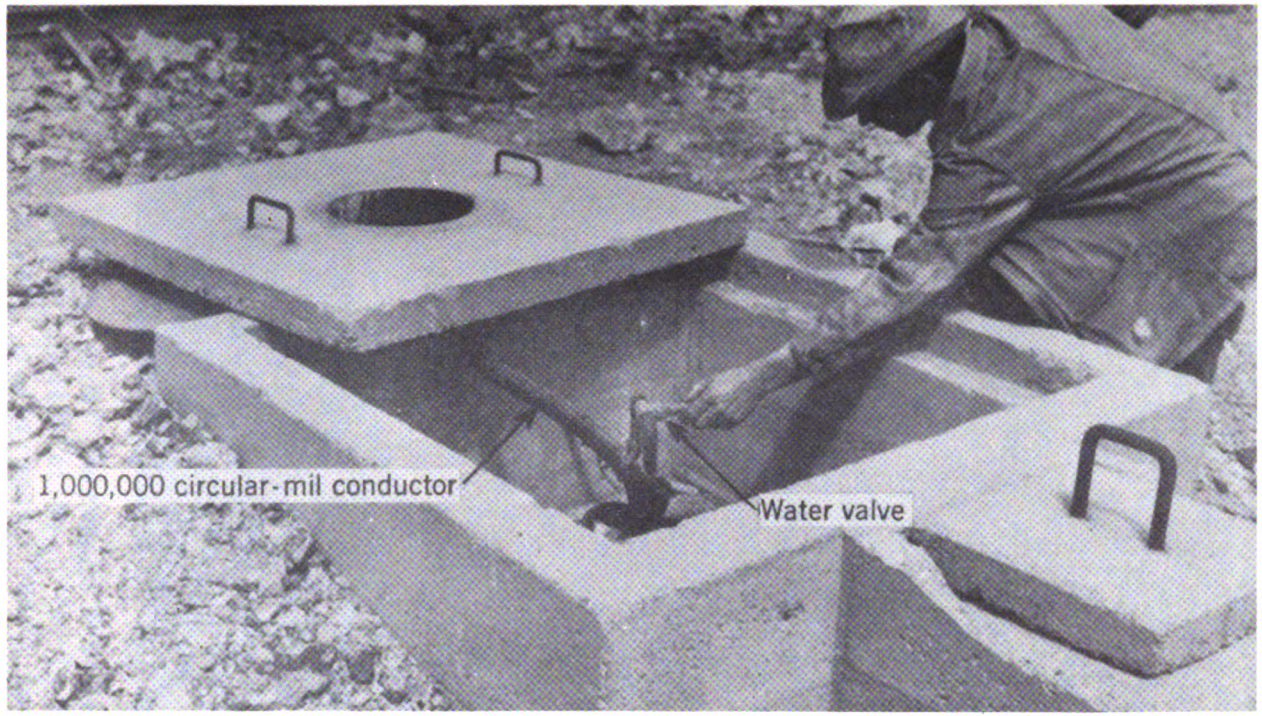

Figure 8. - Ground electrode, 9-inch churn-drill hole 275-feet deep, 1,000,000 circular-mil conductor.

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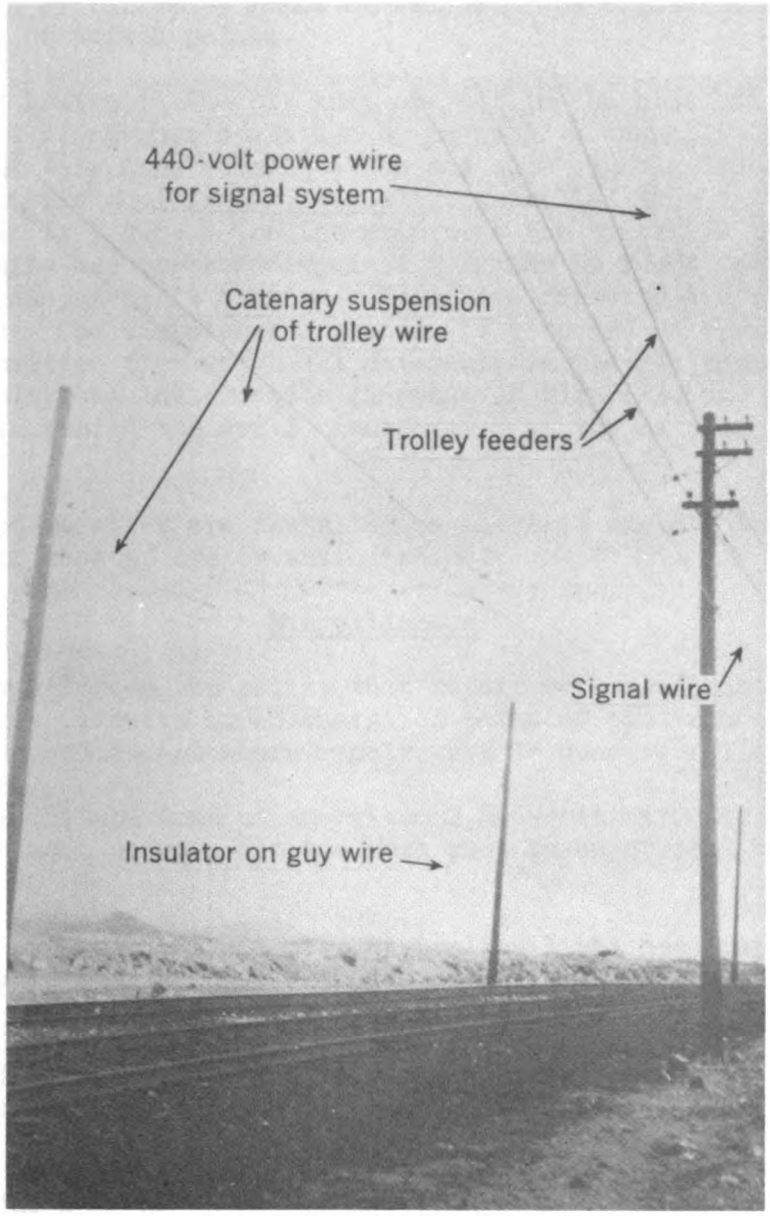

Figure 9. - Trolley wires suspended from cross-catenary installation on double-track haulage; trolley feeders and automatic block-signal circuit wires on poles to right of tracks.

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is down, thus providing a continuous source of power on the signal system. If the power fails completely on both circuits, the red stop lights are energized through batteries by means of relays. The signals also are operated by the alignment of switch points.

Movement of trains in the pit that are not in the block-signal system is controlled from a dispatcher's station by means of a manually operated signal system, including telephone communication and code signals issued by means of a horn. One of the signal lights, manually controlled from the dispatcher's station, is shown in figure 4 (on the pole near the tracks in the background). The signal circuits are protected against overload by fuses installed in the circuits at the dispatcher's station. Telephone circuits are protected by protector blocks. The dispatcher's station is situated on a knoll overlooking the pit, in a position from which all movements in the pit proper can be seen. A typical pit-telephone installation is shown in figure 3, and the telephone booth can be seen behind the drill transformers at the extreme right of the photograph.

Air-operated whistles are installed on electric shovels for directing the "spotting" of cars of ore or waste trains.

Miscellaneous

The company enforces the policy that repair work shall not be done on energized electric circuits or on energized parts of electric equipment. Power is disconnected except where repair work is done as follows:

1. If work must be done on energized 2,300-volt circuits on pole lines, insulated gloves must be worn and the work must be supervised by a qualified foreman.

2. If the 860-volt, direct-current trolley lines need repairs while energized, the work must be done from the portable scaffolds which the company provides.

Under no circumstances is repair work permitted on energized 13,900-volt circuits or equipment.

Systematic inspections of wiring and electrical equipment are made at regular intervals; some of these are as follows:

1. The grounding connections from the frames of the electric shovels and the equipment on the ground protection systems are inspected twice a month. The grounding connections are tested for electrical continuity and the equipment on the ground protection systems are tested to determine whether they are in operating condition.

2. Adjustments of control equipment on shovels are inspected at least once every 6 months.

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3. All electric equipment on shovels is inspected thoroughly and serviced at least once a month.

4. A small crew of electrical maintenance men moves from shovel to shovel each day making minor repairs.

5. Equipment in substations is inspected and serviced each morning, and a log is kept of the temperature, vacuum readings, loads, etc., on the rectifiers.

Warning signs are posted conspicuously wherever specific hazards exist. Figure 10 shows railroad-crossing signs at a grade crossing in the pit. A similar warning sign is also shown at the extreme left of figure 5. A "danger" sign is shown on the door of the switch house in figure 4.

The rear car of each ore train is equipped with a small enclosure for the brakeman for safety. Previously, the brakeman stood on a platform on the end of the last car, but after a loose trolley wire caused a near accident, enclosures were built on the platforms to not only shield the brakemen from broken wires but also to serve as windbreaks and rain shelters. Shatter-proof glass windows on the enclosures provide ample safe visibility. Shovel operators have strict orders to be careful in loading the last car to avoid damaging the enclosure.

Shops are of fire-resistive construction, having concrete foundations and floors and steel-frame and sheet-metal enclosures. Electric-power and lighting circuits are in conduit and protected against overloads by fuses or circuit breakers.

Ample spare parts and equipment are on hand to minimize delays caused by breakdowns, accidents, etc.

MINE B

General Information

Power is purchased from a public utility company; it is transmitted to a transformer station near the mill at 110,000-volts, 25-cycle, alternating current on a structural-steel tower transmission line, which is owned by the public utility company. The high-voltage transmission line is part of a loop in the commercial power system; the mine is thus assured power from two directions or from the equivalent of two separate power lines. A synchronous condenser is installed in the transformer station for voltage-regulation purposes, and overload protection on the power circuits is provided by overload protective devices on oil circuit breakers, which are installed at the station.

The 110,000-volt, 25-cycle, alternating-current power is reduced at the mill transformer stations (outdoor and indoor type) to (1) 6,900 volts for distribution to pit and pit-shop equipment and (2) 2,300, 440, and 110 volts for the mill power and lighting circuits. The circuits are well-protected against overloads by overload protective devices connected to the circuit breakers.

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**Figure 10. - Railroad-crossing warnings.
Note: Bench marker.**

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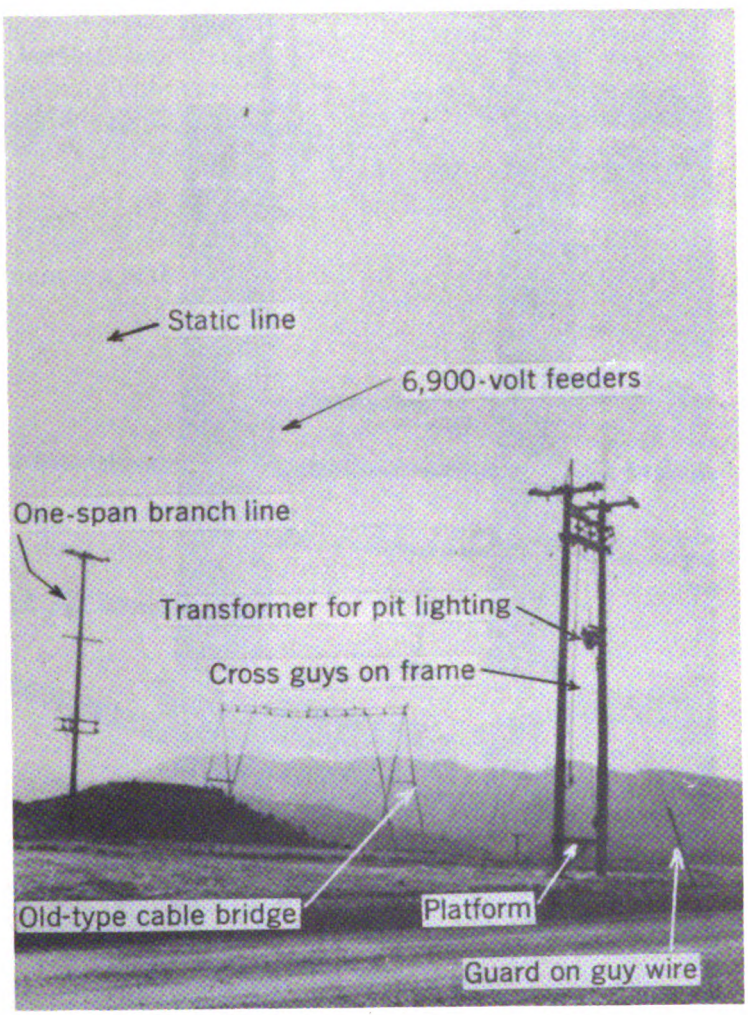

Figure 11. - H-frame for 6,900-volt feeders and one-span branch line. Note: Static line, disconnecting switch, platform, and guard on guy wire.

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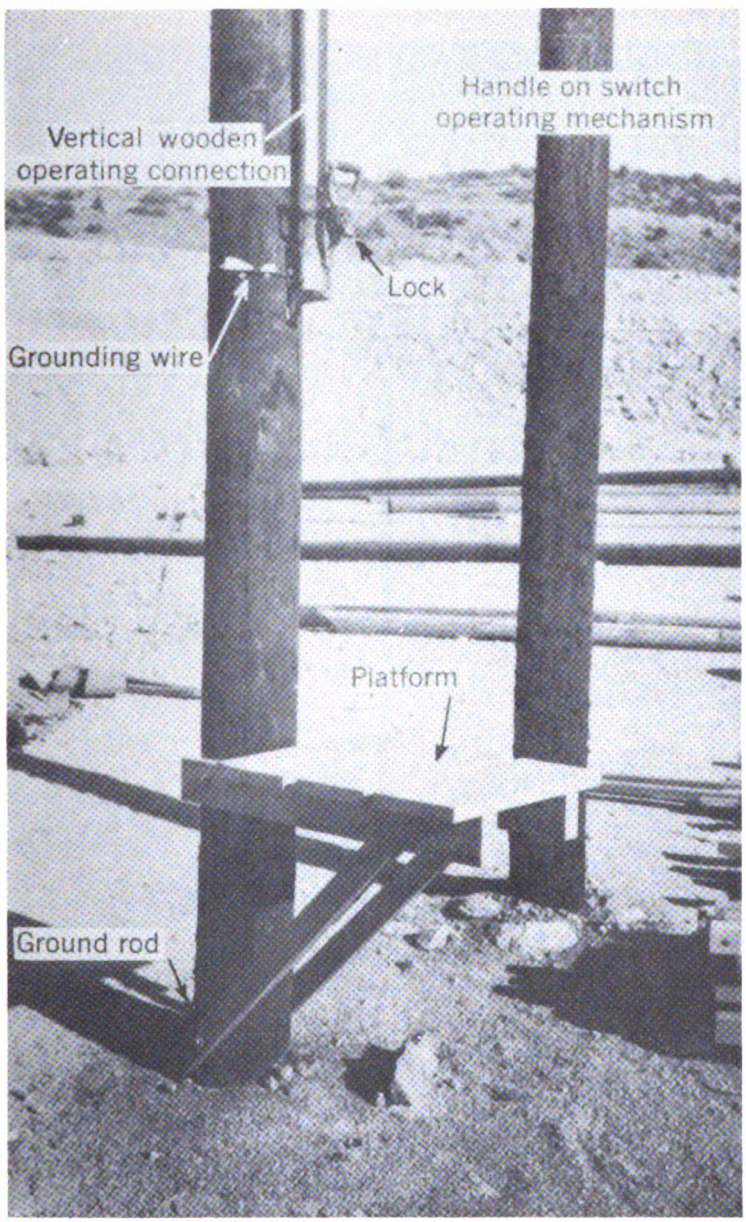

Figure 12. - Handle mechanism on disconnecting switch and insulating platform. Note: Lock and ground connection on handle mechanism.

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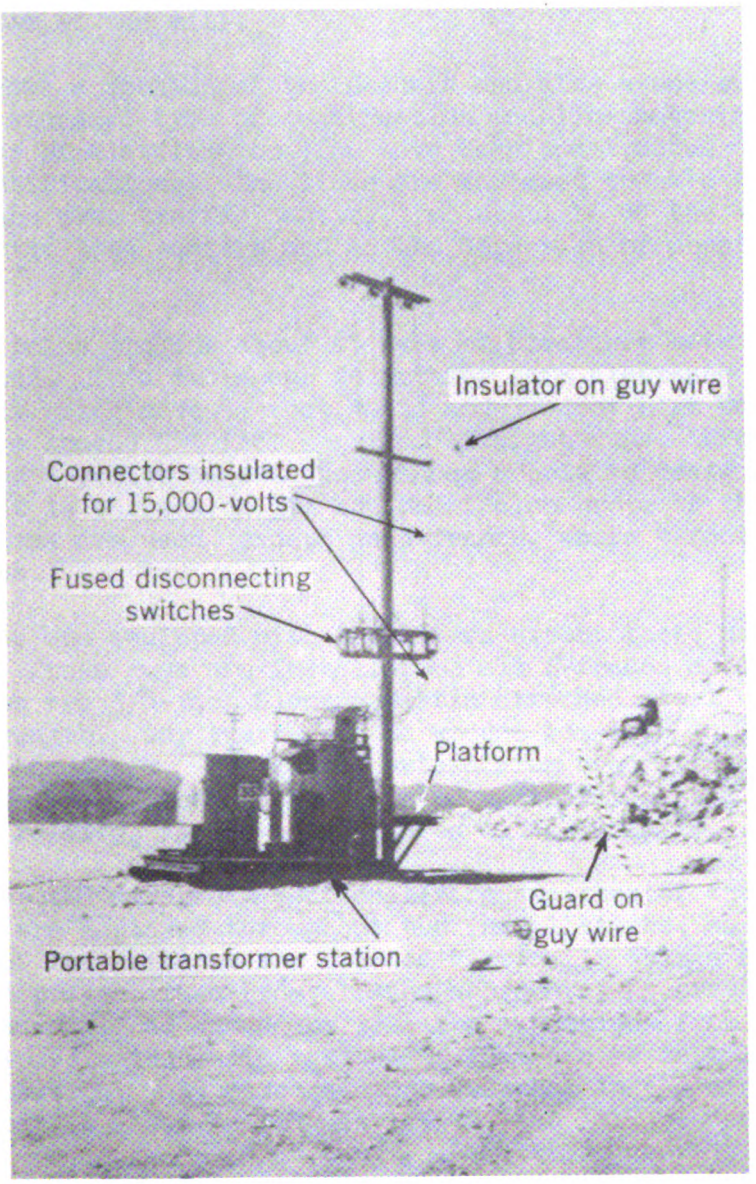

Figure 13. - Portable transformer station - three-phase transformer and switch house mounted on a skid.

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The 6,900-volt, pit-distribution feeders consist of No. 00 stranded copper wires installed on insulators mounted on cross arms on wooden poles. Static lines are installed above all the 3-phase, 6,900-volt feeders and are grounded by guy wires at corners and at other points where feasible, and also to the water system of the mill.

Figure 11 shows a section of the feeders and also a one-span branch circuit showing the standard type of construction and line materials used at the mine. The 2 miles of distribution line have been constructed under medium-light loading specifications. The lines are designed to have the least possible number of spans over traffic centers, yet still be of the shortest practicable route to the load centers and in the direction of possible future loads.

The 50-foot poles provide about 45 feet of clearance between the conductors and the ground. This is enough to provide safe clearance for churn drills and shovels which have 39-foot masts and 37-foot high booms, respectively. Poles are spaced 200 feet apart on straight runs. Cross arms are painted yellow and a yellow band is painted on a pole to designate that a 6,900-volt circuit is carried on it; the paint also protects the arms. Standard 8-foot arms are used, except on H-frames, where 4-foot spacing is used between wires.

All guy wires are equipped with insulators except those used to ground the static line. Cross guys are installed on all H-frames as shown in figure 11. All guy wires are 3/8-inch Siemens-Martin stranded steel cable of 4,090-pound tensile strength. Guy guards of the wooden box-type enclosure are used where considered necessary. The guards extend from a point near the ground to about 6 feet above the ground and are painted white with black stripes, so that they can be seen readily, as shown in figures 11, 13, and 16.

Manually operated air-break sectionalizing switches of the single-throw, triple-pole type are employed throughout the installations, as shown in figure 11. The blades of the switches are mounted vertically (hinge down) as a safety measure to prevent them from closing accidently by gravity from the open positions, as could be caused by pole-top vibrations from blasting. The switches are equipped with handle mechanisms that can be kept locked in the closed or open position. All disconnecting switches in the mine are operated from platforms such as shown in figures 11, 12, and 13.

The close-up view of figure 12 shows the handle of the switching equipment locked in the connected position. Although the vertical-operating connection is of wood, the metallic parts of the handle mechanism are connected by a grounding conductor, to a ground rod at the base of the pole, as shown in figure 12. The handle mechanisms are connected to grounding electrodes, which are separate from those that ground the metallic frames of the switches proper.

A considerable number of lightning-arrester installations have been provided, because severe lightning storms are experienced in the area during the summer months.

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Shovel Transformer Stations

A portable transformer station (fig. 13) furnishes power at a reduced voltage for each of the 5-cubic-yard electric shovels. A 300-kv.-a., 3-phase, 6,900- to 2,300-volt transformer and the switch house for the secondary circuit switching and ground-protection equipment are shown mounted on a steel-frame skid. The 3-phase transformer is closed delta-connected on the primary circuit and Y-connected on the secondary.

As an additional safety precaution, the drops from the top of the pole to the fused disconnecting switches and from the latter to the high-voltage bushings of the transformer are single-conductor cables, varnish-cambric insulated for 15,000 volts. The disconnecting switches are operated from a platform of the type shown at the base of the poles in figures 12 and 13. No work is allowed above the cut-outs if the drops are energized.

A short piece of cable, with conductors insulated for 5,000 volts, connects the low-voltage bushings of the transformer to the oil circuit breaker in the totally enclosed sheet-metal switch house, which, in addition to the breaker, contains overload relays, wattmeter, and the ground-protection equipment. Connections are made through the walls of the switch house by means of well-installed and well-insulated bushings; terminals of bushings on the outside of the switch house are enclosed by locked compartments.

Similar connections on the switch house are used for the trailing cable to the shovel. The metal doors to the back of the switch house are kept locked at all times unless an attendant is present.

"Danger - 6,600 Volts" warning signs are painted conspicuously in large yellow letters on the switch house.

Ground-Protection Equipment

The ground-protection equipment at each transformer station consists of:

1. Single-phase reactor rated at 15 amperes at 1,275 volts for a normal line voltage of 2,500 volts, 25 cycles.

2. Current transformer.

3. Capacitor tripping device.

4. Ground relay.

5. Grounding electrode.

The grounding electrode consists of a copper-clad steel rod 8 feet long driven into the earth near the shovel transformer station. The current transformer and the reactor are connected in series between the grounding electrode and the neutral point of the Y-connected secondary of the shovel transformer. The frame of the shovel is connected by means of ground wires in the trailing

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Figure 14. - Handling a 2,300-volt shovel cable by means of insulated gloves and tongs.

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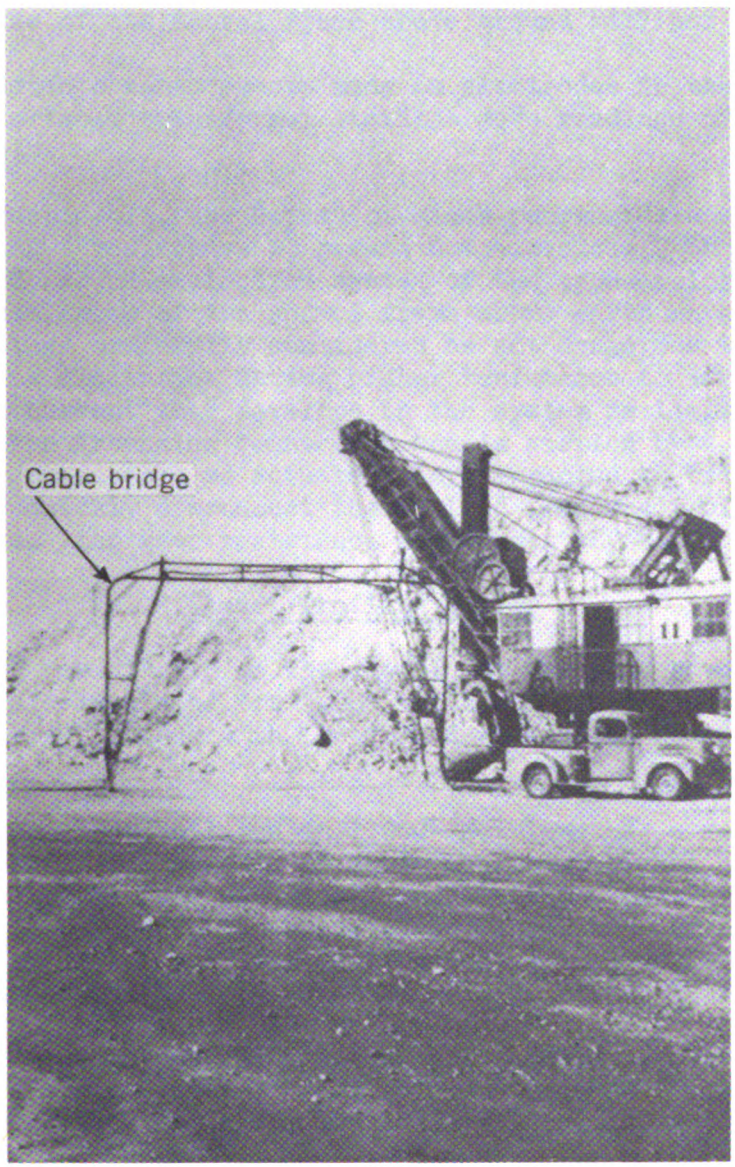

Figure 15. - Bridge for cables.

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cable to the grounding connection at a point between the electrode and the current transformer. The secondary of the current transformer is connected to the ground relay. The capacitor tripping device provides a source of energy for the tripping circuit. The reactor provides an impedance in the grounding connection, limiting the ground fault current to such a value that the potential rise of the shovel frame above ground will not be hazardous.

Ground-resistance measurements made on electrodes in the ground connections of three portable transformer stations gave readings of 23, 31, and 43 ohms, respectively.

Wherever practicable, the Bureau of Mines recommends use of grounding connections having a resistance to ground not exceeding 3 ohms. However, in a well-maintained ground-protection system of the type employed by this company, the potential rise of the shovel frame above earth on ground fault will not exceed a voltage ordinarily considered as not dangerous to human life, although grounding electrodes having higher resistance to earth are used. Any ground-fault current that develops in the system is limited in value by an impedance in the grounding connection and is carried by a continuous circuit of metallic conductors to actuate relays arranged to trip the feeder circuit breaker and quickly disconnect the faulted feeder circuit. A similar test on the static line gave resistance measurement of 2-1/2 ohms.

Shovel Trailing Cables

The trailing cables used on the shovels at the mine have No. 2 shielded conductors that are insulated for 5,000 volts and contain ground wires for connecting the shovel frames with the ground-protection equipment in the switch houses.

The cables are sectionalized in 1,000-foot lengths; a few 350-foot sections have been made from lengths of cable shortened by use and when necessary the shorter lengths are used as extensions. Suitable plug-type connectors are used to couple the cables to the shovels and also to the extension cables. Excess trailing cable for a shovel is kept coiled in a large figure-eight loop at some distance back of the shovel.

The company does not permit damaged cables to be connected to a power source; temporary splices are not permitted. A damaged cable is replaced immediately and taken to the shop, where it is repaired, and all splices are vulcanized.

Energized shovel trailing cables are handled only with rubber gloves and insulated tongs, as shown in figure 14. The gloves, which are insulated for 10,000 volts, are carried on the shovels and on the mine foremen's trucks.

Cable bridges of pipe framing (shown in fig. 15) are used at all road crossings (truck haulage is used at the mine). Inside clearance of a cable bridge is about 15 feet high and 20 feet wide. The cable is hoisted and lowered from the bridging by means of ropes and pulleys. The bridges are

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moved about by the large trucks, which are equipped with a simple but efficient means of picking up the bridges. Each truck has been provided with a heavy sheet-metal hood over the cab as extra protection for the driver; the hood is welded to the dump box and moves up and down with the box. Two "ears" are welded to the top of the hood near its front edge; they are grooved to the curvature of the pipe on the crosspiece of the bridge. In moving a bridge, the truck simply moves under it and picks it up at the "ears" by raising the box. The bridge, when raised off the ground, balances on the hood and can be moved to any desired place.

Drill Transformer Stations

Portable, skid-mounted, totally enclosed transformer stations (shown in fig. 16) are used for drill operations at the mine. Single-conductor cables insulated for 15,000 volts with varnish-cambric insulation are used to connect the transformers to the fused cut-outs and also the cut-outs to the disconnecting switches on the pole. The cut-outs are mounted on a frame on the portable station so as to be 10 feet above the ground. The power is transmitted through the walls of the enclosure by suitably insulated bushings.

An enclosed transformer station houses three 7-1/2-kv.-a., single-phase, 6,900- to 440-volt, closed, delta-connected transformers and a 100-ampere, 575-volt safety switch and a wattmeter connected to the 440-volt circuit. The doors to the enclosure are kept locked unless an attendant is present.

The trailing cable to a drill is connected to the station with a plug connector, as shown in figure 16.

The metallic frames of the equipment in the stations are connected to grounding electrodes (8-foot, copper-clad rods) driven in the earth nearby.

Drills and Trailing Cables for Drills

Trailing cables for drills contain three No. 4 power conductors and ground wires. The ground wires are used to connect the frames of the drills with the ground circuit at the transformer station. Plug-type connectors are used for making connections at both the transformer station and at the drill. The connections are made or opened only when the cables are deenergized, to avoid the hazard of making or breaking connections under load.

Cables are sectionalized in 1,000-foot lengths. Damaged drill cables are not tolerated in energized circuits, and temporary splices are not made. Damaged cables are replaced immediately and sent to the shop for repair, splicing, and vulcanizing.

Insulated gloves of the type used to move shovel cables are available at each drill; the gloves must be used when handling energized cables.

Figure 17 shows a drill with the excess trailing cable neatly coiled at the side of the all-metal housing at the rear of the drill; the housing also encloses the motor and control equipment. Coiling in long loops, as shown, prevents excessive heating of the cable.

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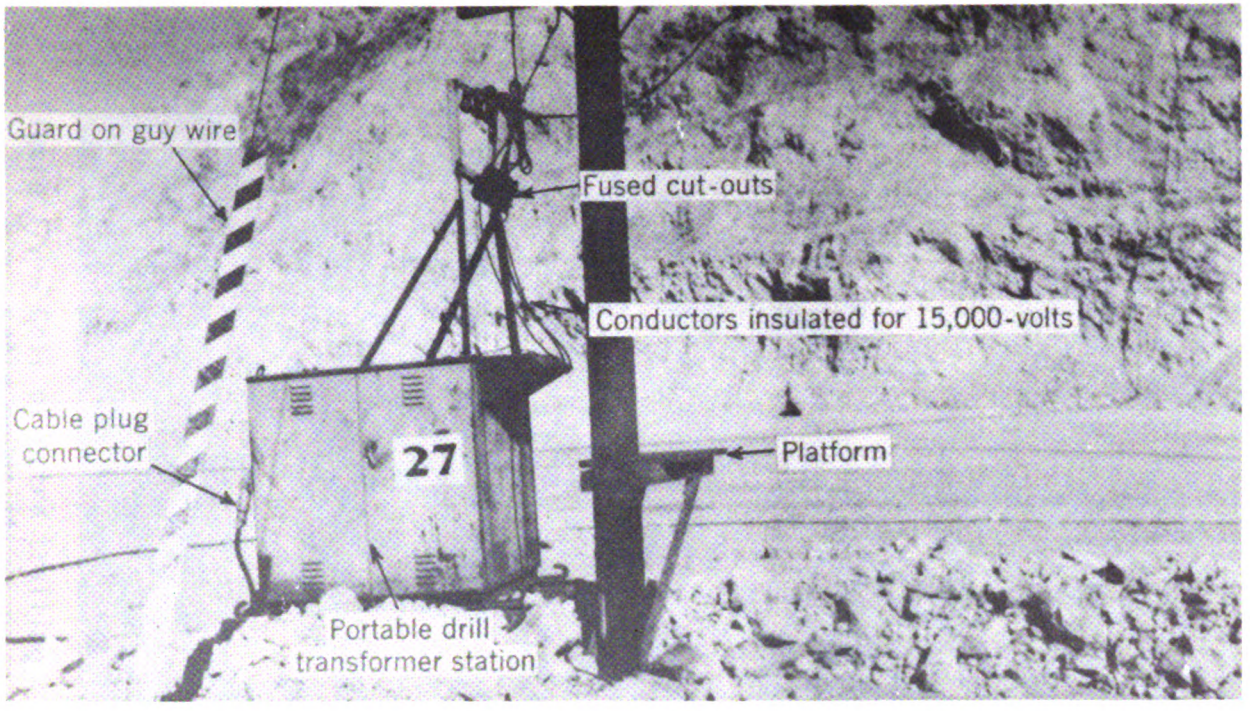

Figure 16. - Portable drill transformer station.

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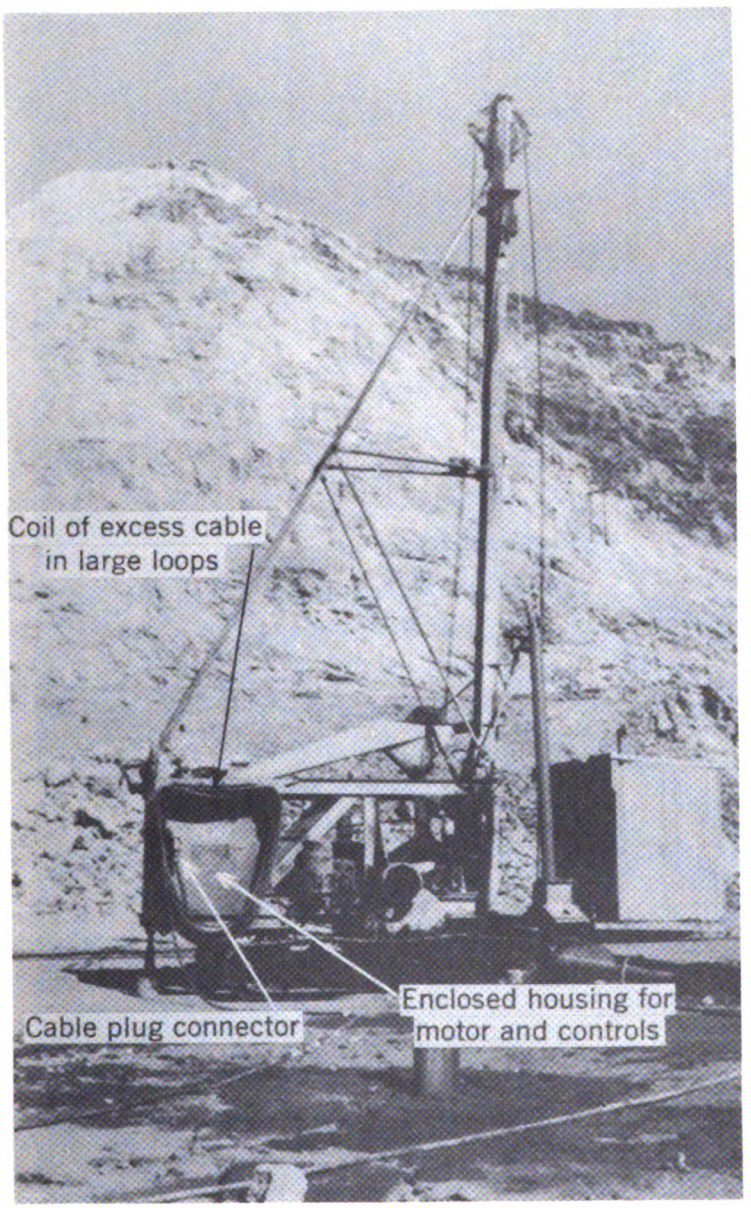

Figure 17. - Coil of extra trailing cable on drill.

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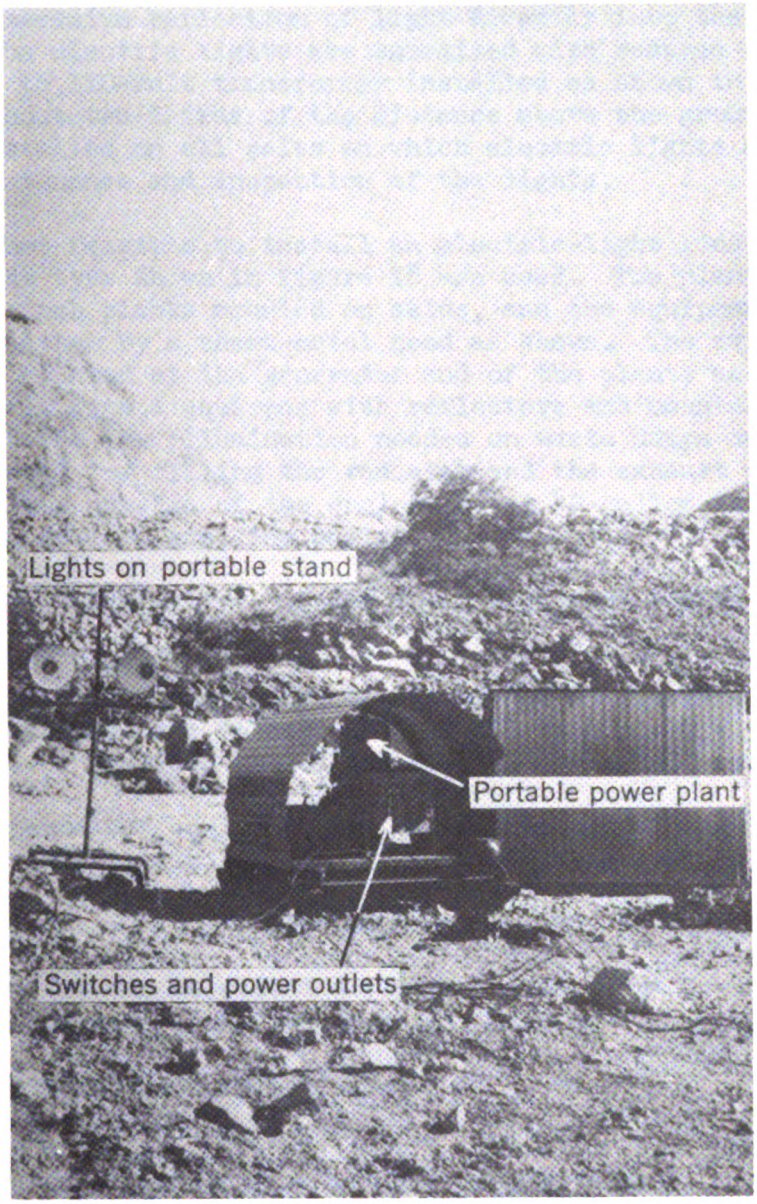

Figure 18. - Portable power plant - generator driven by a gasoline engine.

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Miscellaneous

Electric lights have been provided on the truck approach from the pit to the mill. The light reflectors are mounted on brackets on poles in position to prevent excessive reflection of light directly into the eyes of the truck drivers. The electric lights are energized with reduced voltage provided by a 6,900- to 110-volt transformer installed as shown in figure 11 (on the H-frame about two-thirds of the distance above the ground). Steel-pole steps are installed on all poles on which electric lights are mounted, to facilitate maintenance and inspection of the lights.

Where it is not feasible to install an electric-light line, portable power plants of the type shown in figure 18 are used. The plant equipment is installed on 2-inch planks mounted on skids, and the equipment is protected from the weather by a sheet-metal hood as shown. The switches and power outlets are mounted at the generator end of the plant, as shown in figure 18. Electric lights equipped with reflectors and mounted on a portable pipe stand provide the illumination needed on waste dumps and in similar areas. The pipe used for filling the radiator and the exhaust pipe from the engine extends to the outside of the enclosure. A 40-gallon tank provides ample fuel storage for the gasoline engine.

"Danger - High-Voltage Line - Lower Boom" signs are posted conspicuously where required.

Modern fire-resistive shops have been provided at the mine. Electric circuits in the buildings are in conduit, and all circuits are protected for overloads by fuses or overload protective devices on circuit breakers.

Ample spare parts and equipment are on hand to minimize delays caused by breakdowns, accidents, etc.

CONCLUSIONS

In conclusion, it can be stated definitely that electrical hazards have been reduced to a minimum at the two open pit mines by:

1. The selection of proper equipment.
2. Adequate insulation.
3. Proper installation.
4. Enclosure or elevation of current-carrying parts.
5. Ample working space around equipment.
6. Locking switches under certain conditions.
7. Using identifying and warning devices.
8. Protective grounding.
9. Use of insulating flooring, platforms, or rubber gloves.
10. Regular inspection and maintenance.

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In addition, the directing heads of the companies have:

1. Placed competent men in charge of the electrical equipment, under whose charge are experienced and well-trained crews.

2. Established adequate safety departments to instruct employees, conduct safety courses, and enforce safety rules.

3. Provided proper and ample maintenance supplies.

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